1. INTRODUCTION[1]

Shipboard Scientific Party[2]

The Labrador Sea and Baffin Bay are small ocean basins confined between the coasts of Labrador and Baffin Island on the west and Greenland on the east (Fig. 1). The two basins are separated by the sill at Davis Strait, which is no deeper than 700 m. Today the Labrador Sea and Baffin Bay form the western branch of the North Atlantic Ocean. The eastern branch of the North Atlantic is composed of the Reykjanes Basin and Greenland–Norwegian Seas, which are separated by a sill from the North Atlantic by the Greenland–Scotland Ridge, having passages (such as the Denmark Strait) as deep as 700 m. Before the formation of the Greenland–Norwegian Seas in the late Paleogene, the Labrador Sea and Baffin Bay perhaps formed the main conduit between the Arctic and Atlantic oceans, at least for surface-water mass exchange. Thus, the Labrador Sea and Baffin Bay provide excellent localities for studying the early tectonic and paleoceanographic history of the North Atlantic and its connection to the Arctic Ocean through time. Leg 105 was designed to address some important problems, as follows:

1. Drilling in the Labrador Sea and Baffin Bay margins provides an opportunity to study conjugate continental margins and the geological characteristics of a continental rift zone before and shortly after the beginning of seafloor spreading. Baffin Bay is one of the few passive margins having syn-rift and early post-rift sediments accessible to drilling. Knowledge of the depositional environment and the age of these sediments is important for modeling the tectonic history and associated crustal movements of passive margins. Of course, Baffin Bay could be considered anomalous in that it is a failed rift, and some debate has arisen about whether seafloor spreading ever formed oceanic crust in this basin.

2. During Cretaceous through Eocene time, the Labrador Sea and Baffin Bay may have been a corridor for the exchange of Arctic and Atlantic waters, but the exact configuration and paleobathymetric regime of this ocean seaway are not well known. Analog circulation models and scant micropaleontological data from shelf exploration wells suggest that surface circulation was directed toward the Arctic Ocean. However, it has also been postulated that during that time and later, circulation was from the Arctic to the Atlantic through Davis Strait. Additional micropaleontological data from the Labrador Sea and Baffin Bay will help to distinguish between these two hypotheses. Furthermore, these regions also provide an outstanding opportunity to study the style and rate of change from pelagic-hemipelagic sedimentation to deep-current-influenced deposits. The deep benthic turn-over at the Eocene/Oligocene boundary has been interpreted as a function of more vigorous deep circulation during global late Eocene–Oligocene cooling and generation of colder deep-water masses in the Norwegian Sea concurrent with subsidence of the Greenland–Scotland Ridge.

3. The Labrador Sea and Baffin Bay, the major moisture sources to the Laurentide and Greenland–Innuitian ice sheets, lie adjacent to the major outlets of these ice sheets. These seas span the critical range of latitudes (55°–70°N) over which the dominant frequencies in the insolation responses are predicted to change from 23,000 yr (precessional variation) to 41,000 yr (obliquity variation). Hence, continuous late Cenozoic–Quaternary sequences in this area should allow testing of diverse theories regarding the causes of glaciation and the forces behind glacial-interglacial cycles.

4. Micropaleontological studies of continuously cored sequences from these basins will examine the evolutionary responses of the marine organisms to and the timing of rapid and extreme paleoenvironmental–paleocirculation changes associated with both the Eocene–Oligocene event and the late Cenozoic global climate deterioration, as well as provide ties between low- and high-latitude biostratigraphic zonations in the Atlantic.

5. Finally, the relatively small size of these basins and the availability of data from the exploratory wells drilled on their continental shelves and slopes should make these fruitful areas for studies of sediment budgets and sedimentary response to sea-level changes, subsidence, paleocirculation changes, and glacial and interglacial cycles.

Thus, the objectives for Leg 105 were threefold: (1) to study the tectonic development of these basins, (2) to study the history of surface- and deep-water paleocirculation through these regions and their connection to the Arctic and Atlantic oceans, and (3) to study the paleoclimatic conditions and timing and

[1] Srivastava, S. P., Arthur, M., Clement, B., et al., 1987. *Proc., Init. Repts. (Pt. A), ODP*, 105.

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frequency of climatic oscillations, particularly glacial and interglacial cycles, which prevailed in these regions. Details of these objectives together with some background information on the geological and paleoenvironmental setting of these basins are described in the following text.

Tectonic Evolution of the Labrador Sea and Baffin Bay

The chronology of the tectonic evolution of the Labrador Sea and Baffin Bay is not precisely known despite the numerous wells drilled on their continental shelves and slopes and the large amount of geophysical and geological data collected in these regions. The difficulty lies in correlating the magnetic anomalies through these regions and in relating them to the well-developed and easily recognized anomaly patterns in the rest of the North Atlantic. Deep Sea Drilling Project (DSDP) Leg 12 (Laughton et al., 1972) attempted to date these anomalies by drilling a hole on a basement high on suspected anomaly 26 crust (DSDP Site 112). However, only a weathered section of basalt was recovered; thus, no satisfactory radiometric age could be determined from the sample. The sediments immediately overlying the basalt were devoid of microfossils and, therefore, could not provide a minimum age for the underlying basement rocks.

The geology of the Labrador Shelf and parts of the West Greenland Shelf, however, is well known from 20 exploratory wells drilled on the Labrador Shelf, 2 wells near Davis Strait, and 5 wells on the West Greenland Shelf (Fig. 1). The idea that these basins were formed by seafloor spreading (Kristoffersen and Talwani, 1977; Srivastava, 1978; Srivastava and Tapscott, 1986) beginning in the Late Cretaceous (younger part of Chron C34, about 85 Ma) and ending during the early Oligocene (pre-Chron C13, 36 Ma) is congruous with the subsidence of the margin as obtained from these drilling results (Keen, 1979). Extensive multichannel seismic coverage on the shelf and limited lines across the deep basin have helped in tying the pre-Miocene stratigraphic sections on the shelf to deep-basin stratigraphy. This stratigraphic framework is further constrained by an extensive grid of single-channel seismic profiles in the deep basin. However, many uncertainties remain in the correlations outlined so far. Detailed regional magnetic and gravity coverage was completed during the last decade (Figs. 2 through 4), and these together with the seismic information serve as the primary source of information on the geological evolution of these basins. On the basis of the identification and correlation of magnetic anomalies not only in the Labrador Sea but also in the Norwegian-Greenland Sea, Eurasian Basin, and North Atlantic (Srivastava and Tapscott, 1986; Fig. 5), the following scenario for the evolution of the Labrador Sea emerges:

1. Spreading in the North Atlantic south of the Charlie Gibbs Fracture Zone started in the Early Cretaceous (Hauterivian) with the separation of Iberia from the Grand Banks of Newfoundland. Iberia, which at this time was rigidly coupled to Africa, was rotating with Africa, creating the Bay of Biscay. Iberia continued moving as an element of the African plate until mid-Oligocene time (Chron C10), when it started to move with Eurasia.
2. Although initial separation of Greenland from North America may have started during mid-Cretaceous time, active spreading did not start in the Labrador Sea until the Late Cretaceous (Campanian). Little or no spreading took place in the Baffin Bay region during this period. Extensional tectonism did occur, however, as evidenced by the presence of Late Cretaceous basalt at Hekja well (Klose et al., 1982) southwest of Baffin Island and Nukik 2 well (Rolle, 1985) on the West Greenland Shelf.
3. After the separation of Greenland from Eurasia about Chron C25, the direction of spreading changed in the Labrador Sea and Baffin Bay, as manifested by the trends of fracture zones (Fig. 4). Spreading became progressively more oblique from the southern Labrador Sea to Baffin Bay, causing motion in

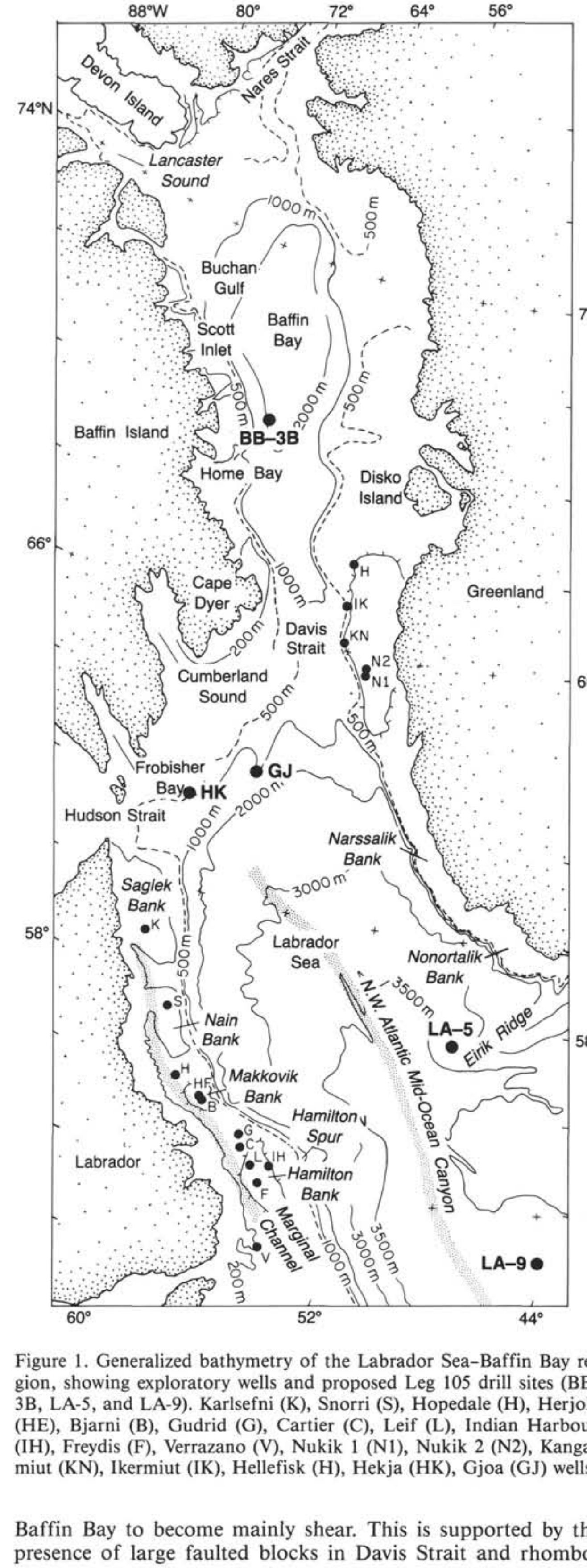

Figure 1. Generalized bathymetry of the Labrador Sea–Baffin Bay region, showing exploratory wells and proposed Leg 105 drill sites (BB-3B, LA-5, and LA-9). Karlsefni (K), Snorri (S), Hopedale (H), Herjolf (HE), Bjarni (B), Gudrid (G), Cartier (C), Leif (L), Indian Harbour (IH), Freydis (F), Verrazano (V), Nukik 1 (N1), Nukik 2 (N2), Kangamiut (KN), Ikermiut (IK), Hellefisk (H), Hekja (HK), Gjoa (GJ) wells.

Baffin Bay to become mainly shear. This is supported by the presence of large faulted blocks in Davis Strait and rhombochasms, as seen in the seismic records (Klose et al., 1982; Srivastava et al., 1982; Srivastava, 1983), and by gravity and magnetic

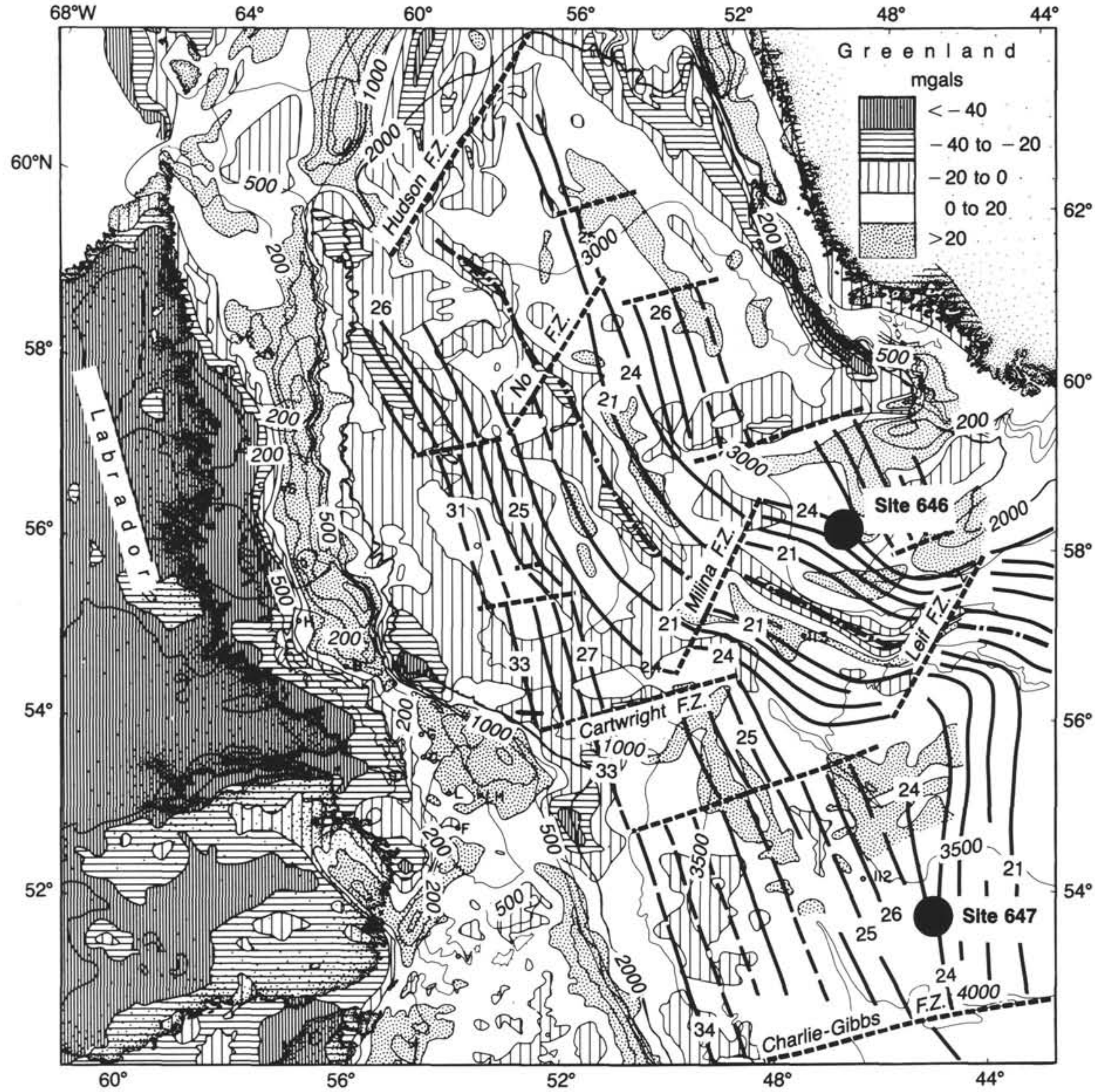

Figure 2. Patterns of magnetic lineations and gravity anomalies near ODP sites in the Labrador Sea. Bathymetry in meters.

observations in this region (Fig. 3). Just before or during this period, a large amount of basalt erupted across at least the Davis Strait region and in the region of Disko Island on West Greenland.

4. Spreading appears to have continued in the Labrador Sea and Baffin Bay in this fashion until Chron C20 but at a much reduced rate. Ultimately, spreading stopped before Chron C13 (Oligocene), a period marked by a magnetically quiet zone in the central part of the Labrador Sea. The quiet zone is symmetrical around a pronounced gravity low, which overlies a rift zone seen in the seismic-reflection lines (Hinz et al., 1979), marking the location of the extinct ridge axis.

Unlike the Labrador Sea, the evolution of Baffin Bay is poorly constrained because of the lack of high-density magnetic and seismic data throughout Baffin Bay and the few drill-hole data north of Davis Strait. Arguments concerning the formation mechanisms of Baffin Bay either through spreading (Srivastava et al., 1981; Keen and Pierce, 1982; Rice and Shade, 1982) or foundering (Kerr, 1967; Grant, 1982) are thwarted by a lack of stratigraphic information from recovered and dated continuous sections of Baffin Bay sediments.

Sparse geological and geophysical measurements made in the bay support the idea that it was formed by seafloor spreading. These include results from the deep exploratory wells drilled to the south in the Davis Strait region off West Greenland (Rolle, 1985) as well as off Baffin Island (Klose et al., 1982). Seismic-refraction measurements throughout the bay (Keen and Barrett, 1972), some detailed gravity and magnetic measurements in the center of the bay (Jackson et al., 1979), and a limited number of seismic-reflection measurements across it (McWhae, 1981; Rice and Shade, 1982) also support the seafloor-spreading hypothesis. Two of the wells off Greenland (Hellefisk and Nukik 2) and two off southern Baffin Island (Hekja and Gjoa) bottomed in Paleocene to Late Cretaceous subaerial to subaqueous basalt flows. These flows form the offshore extension of Tertiary basalt that lie on land on the west coast of Greenland and southern Baffin Island (Clarke and Upton, 1971; Clarke and Pedersen, 1976). Widespread occurrences of early Tertiary to Late Cretaceous basalt throughout the Labrador Sea and Baffin Bay

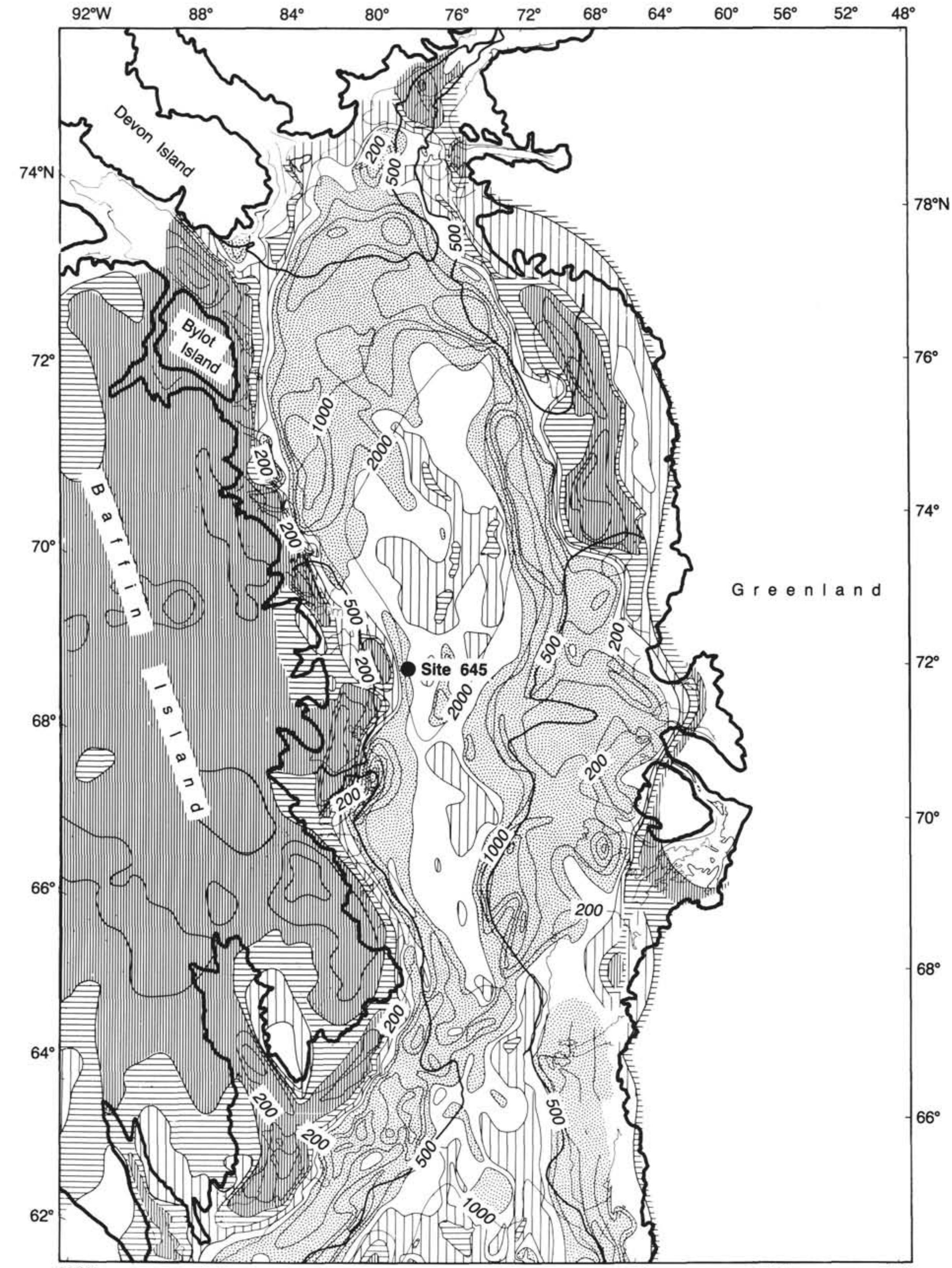

Figure 3. Free-air gravity anomaly map of Baffin Bay. Anomalies shown on land are Bouguer anomalies. Contour interval, 20 mgal. For stippling legend, see Figure 2.

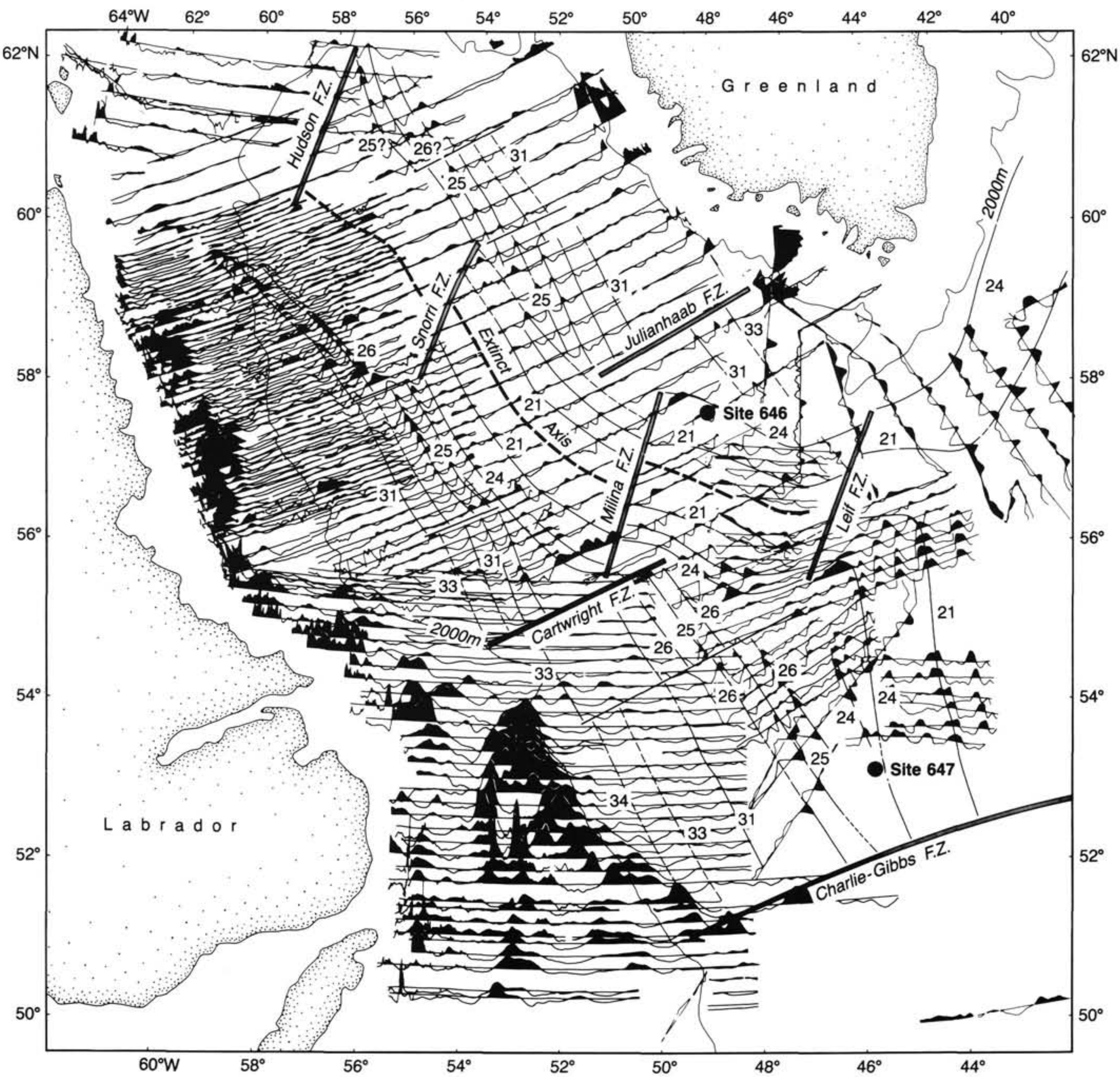

Figure 4. Patterns and correlation of seafloor-spreading-generated magnetic anomalies in the Labrador Sea (from Srivastava and Tapscott, 1986). Shown also are locations of Leg 105 sites.

fits rather well with the time of opening of these regions as obtained from seafloor-spreading models.

Results of a substantial number of seismic-refraction measurements made in Baffin Bay (Keen and Barrett, 1972; for details see Srivastava et al., 1981) show that the crust under the bay is abnormally thin (4 km for the bay crust versus 7 km for normal oceanic crust), and velocities corresponding to layer 2 (between 4.5 and 5.5 km/s) are absent (Fig. 6).

Strictly speaking, seismic-refraction results do not support or refute a seafloor-spreading hypothesis for the bay. However, when combined with detailed gravity, magnetic, and seismic-reflection measurements, the oceanic nature of the crust underlying most of Baffin Bay is indicated by the seismic-refraction data. The most supportive evidence of the oceanic nature of the crust comes from the detailed gravity and magnetic measurements made in the center of the bay, as shown in Figure 7. The measurements show the presence of a gravity low that is coincident with a grabenlike feature seen in one of the multichannel seismic lines (Fig. 6) shot in this region (McWhae, 1981; Srivastava et al., 1981). This gravity low is probably associated with the axis of an extinct ridge in this region, similar to what is observed in the Labrador Sea. The low does not form a continuous feature but is broken into segments, most likely resulting from highly oblique motion between plates in this region (Srivastava and Tapscott, 1986). Site 645 (BB-3B) lies immediately southwest of one of these lows near the margin of Baffin Bay (Fig. 3). Magnetic measurements (Fig. 8) in the detailed survey area show the presence of some lineations, tentatively identified as anoma-

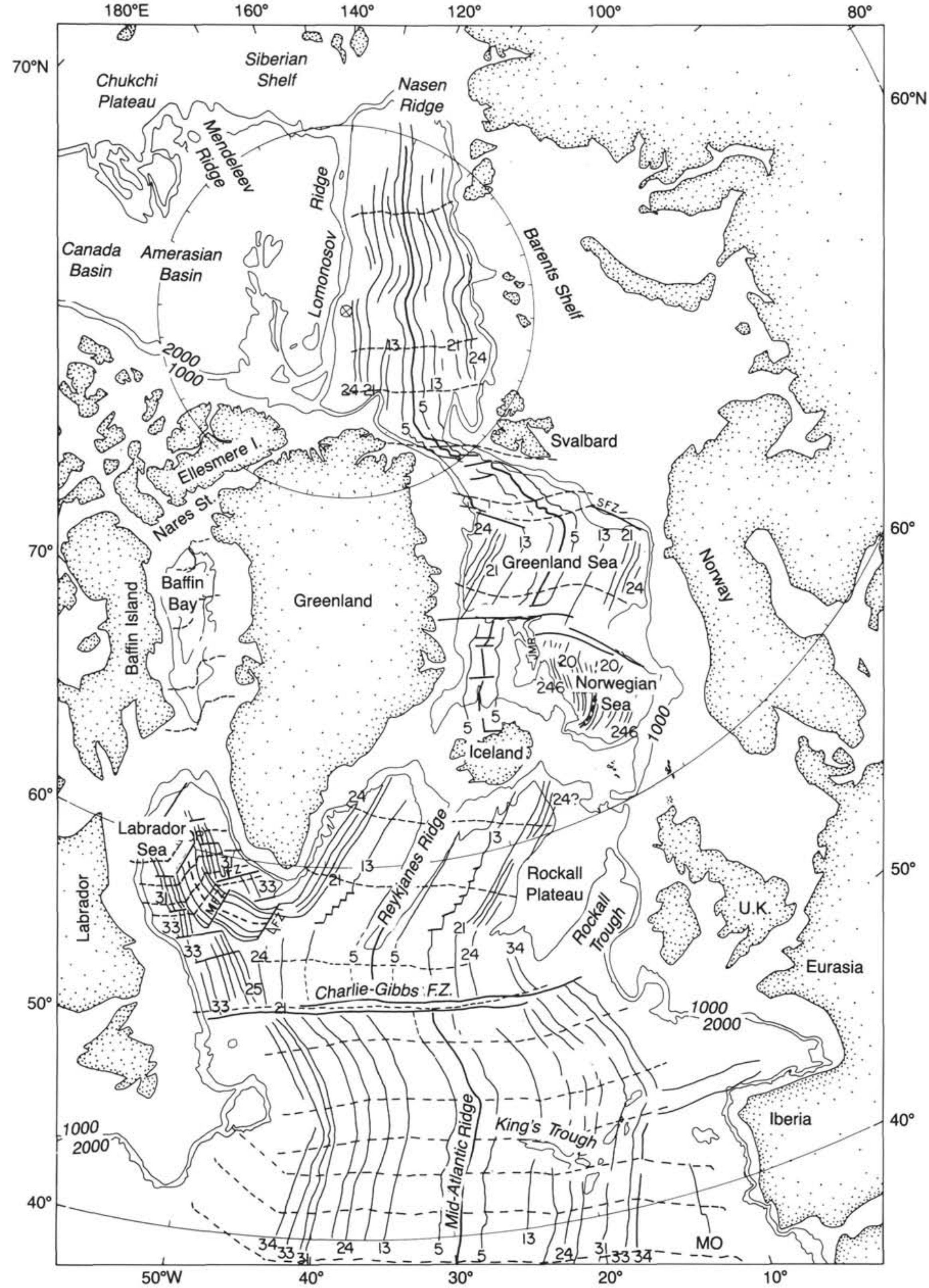

Figure 5. Magnetic lineations and fracture zones in the North Atlantic, Labrador Sea, Norwegian–Greenland Sea, and the Eurasian Basin. Shown also are the flow lines (dashed lines) in the regions (from Srivastava and Tapscott, 1986).

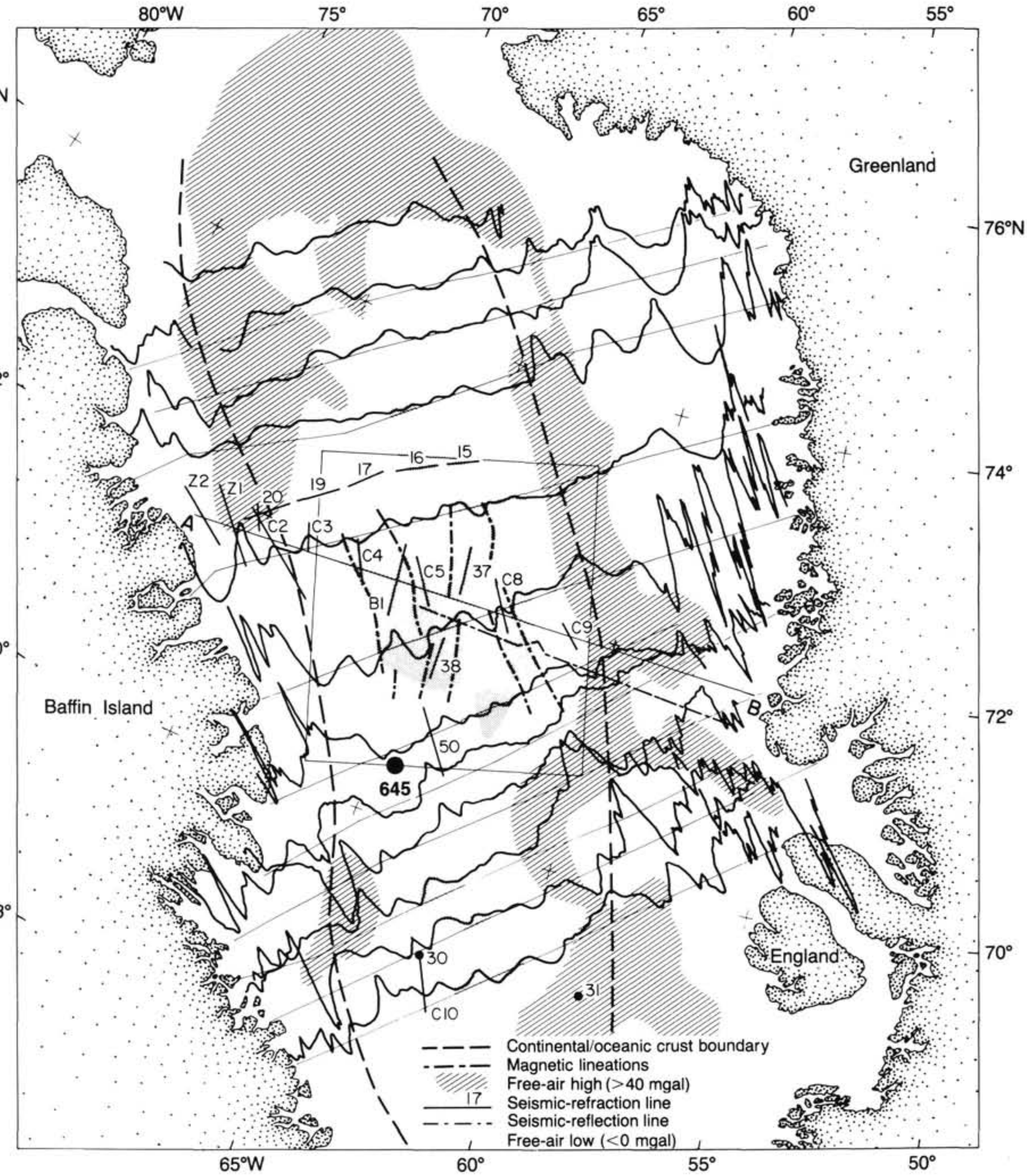

Figure 6. Map showing gravity and aeromagnetic data near ODP Leg 105 drill site BB-3B (Site 645) in Baffin Bay (from Srivastava et al., 1981).

lies 20 to 24 by Jackson et al. (1979), which lie at oblique angles to the direction of motion in this region.

To establish the tectonic history of the Labrador Sea and Baffin Bay regions, two drilling sites in the Labrador Sea (LA-5, Site 646; LA-9, Site 647) and one in Baffin Bay (BB-3B, Site 645) were selected. The Labrador sites (Figs. 1 and 4) are near magnetic anomaly 24, where it was hoped that drilling to basement would allow first-order dating of the magnetic-anomaly sequence, thereby resolving much of the uncertainty in the timing of seafloor spreading in this region. Much of the Labrador Sea is covered by a large thickness of sediments where basement cannot be reached. Thus the older part of the crust cannot be dated directly.

Sediment thicknesses in most parts of Baffin Bay exceed 5 km, thereby rendering the basement inaccessible to drilling with present technologic and time limitations. Presumed syn-rift and early post-rift sediments, however, lie at sub-bottom depths of less than 2000 m at the BB-3B site. We hoped that recovery of Paleocene and possibly Late Cretaceous sediments from this site would provide information on the age and subsidence history of early post-rift sediments, which are important for deciphering the tectonic history of this region.

The aforementioned sites were selected to provide data documenting the tectonic development, paleoclimate, and paleocirculation of these regions, which are discussed in the following text.

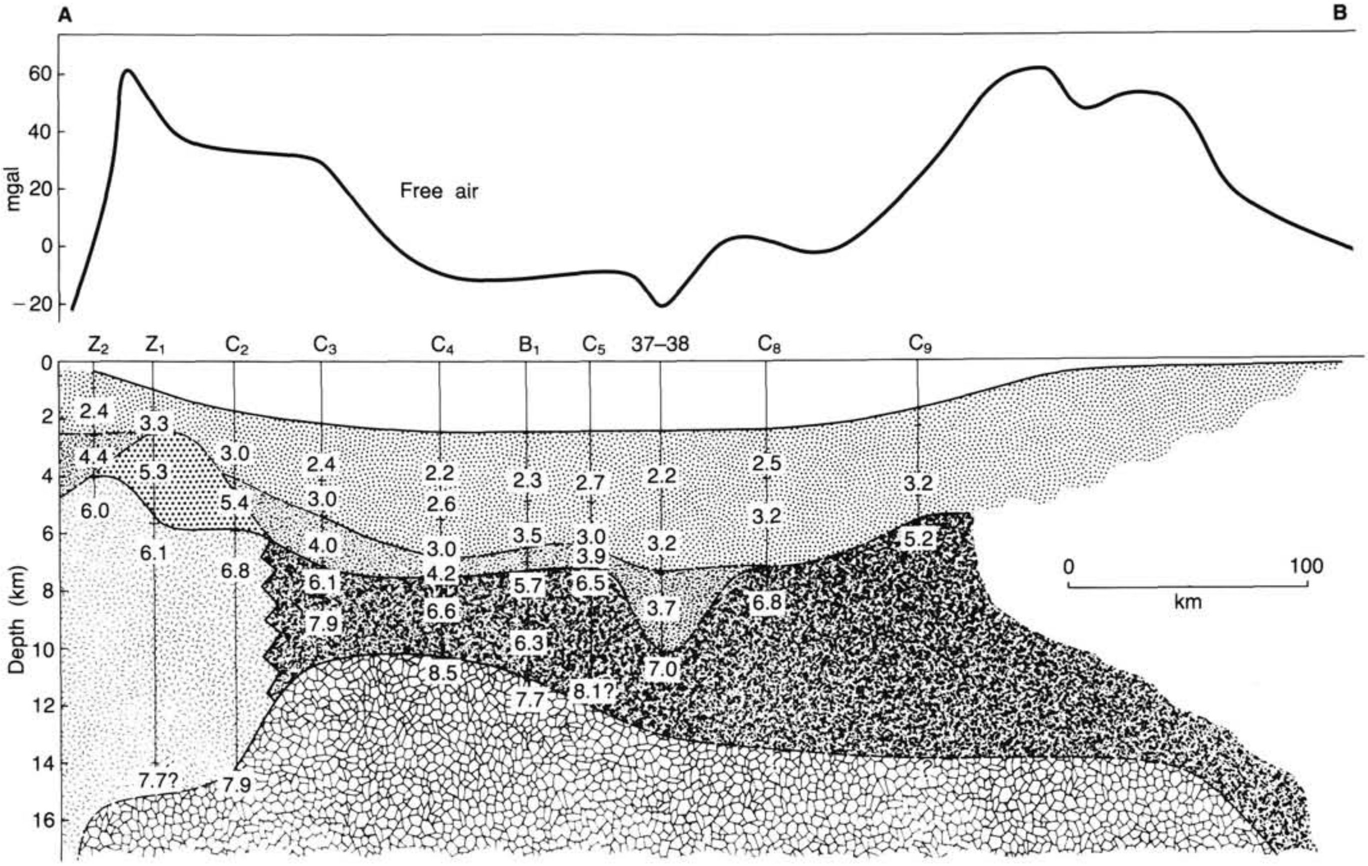

Figure 7. Cross section of Baffin Bay, according to seismic-refraction velocity measurements of Keen and Barrett (1972), Jackson et al. (1977), and Jackson et al. (1979) and seismic-reflection measurements of McWhae (1981). The free-air anomaly over it is shown (from Srivastava et al., 1981).

PALEOCLIMATE AND PALEOCEANOGRAPHY

One of the major objectives of the drilling at the Labrador Sea and Baffin Bay sites was to examine the record of high-latitude paleoclimates, climatic evolution, and surface- and deep-water circulation of the Paleogene through the Quaternary. The sites provide a north-south transect linking events at 70°N with those at about 55°N in the eastern North Atlantic previously drilled during DSDP Leg 94 and others. A rough east-west transect is provided by industry wells on the Labrador Shelf, by Site 647, and by the DSDP Leg 94 sites. This transect allows comparison and correlation with drill sites in the Norwegian Sea (Eldholm, Thiede, Taylor, et al., in press).

The Baffin Bay site (645, Fig. 1) is in a region of high sedimentation rates in the southern part of Baffin Bay, where we hoped to obtain a fairly continuous sequence enabling high-resolution studies of approximately the last 60 m.y. of paleoclimatic history. Site 645 is currently north of 70°N, and little change in paleolatitude has occurred since the Late Cretaceous. The Labrador Sea sites (Fig. 4), both situated on what is interpreted as being magnetic anomaly 24 (early Eocene crustal age), are on either side of the extinct ridge that ceased spreading at about Chron C13 (earliest Oligocene). Thick sedimentary sequences occur at both sites; Site 646 is on the northwestern flank of the Eirik Ridge (Fig. 1), which is apparently a constructional, bottom-current-generated feature, and Site 647 is on the southern flank of the Gloria Drift, also a bottom-current-generated deposit. The Labrador Sea sites were chosen to avoid thick turbidite sequences that characterize the region of the Northwest Atlantic Mid-Ocean Canyon (NAMOC) and also to allow high-resolution stratigraphic studies and timing of the onset of both major turbidite deposition and of deep-current-influenced sedimentation in the Labrador Sea.

Paleogene Paleoclimate and Circulation

The Paleogene saw the continuation of predominantly warm, equable global climates. A variety of evidence suggests that subtropical to temperate climatic conditions existed at least as far as 70°N during the Paleocene and most of Eocene time. Laterites and bauxites, both reflecting intense chemical weathering in warm, predominantly humid climates, are found as far north as 45°N paleolatitude in Paleocene-Eocene deposits (e.g., Van Houten, 1982; Nilsen, 1983). This is substantially farther north than such conditions extend at present. In addition, abundant and widespread lignites and Eocene paleofloras suggest higher latitudinal extent of high precipitation (in Australia; Kemp, 1978; and coal seams in Eclipse Trough on Bylot Island, Arctic, Canada; Miall et al., 1980). Two exploratory wells drilled in the Davis Strait region (Hekja 0-71 and Gjoa G-37 wells; Klose et al., 1982) and five industrial wells drilled on the West Greenland Shelf as far north as nearly 68°N (Rolle, 1985; Fig. 1) encountered lignitic beds within Paleocene-Eocene fluviodeltaic sequences. Clay mineral assemblages in Paleocene-Eocene sediments from the Davis Strait and West Greenland wells also contain substantial amounts of kaolinite (Klose et al., 1982; Hiscott, 1984; Rolle, 1985), and soil horizons on Precambrian basement recovered in some West Greenland wells are primarily kaolinitic. Although much of the kaolinitic weathering, and indeed the kaolinite mixed with other clay minerals in the Paleogene strata, could have been inherited from a previous weathering cycle (e.g., in the Early Cretaceous; Hiscott, 1984), the abundance of kaolinite might be related to predominantly warm,

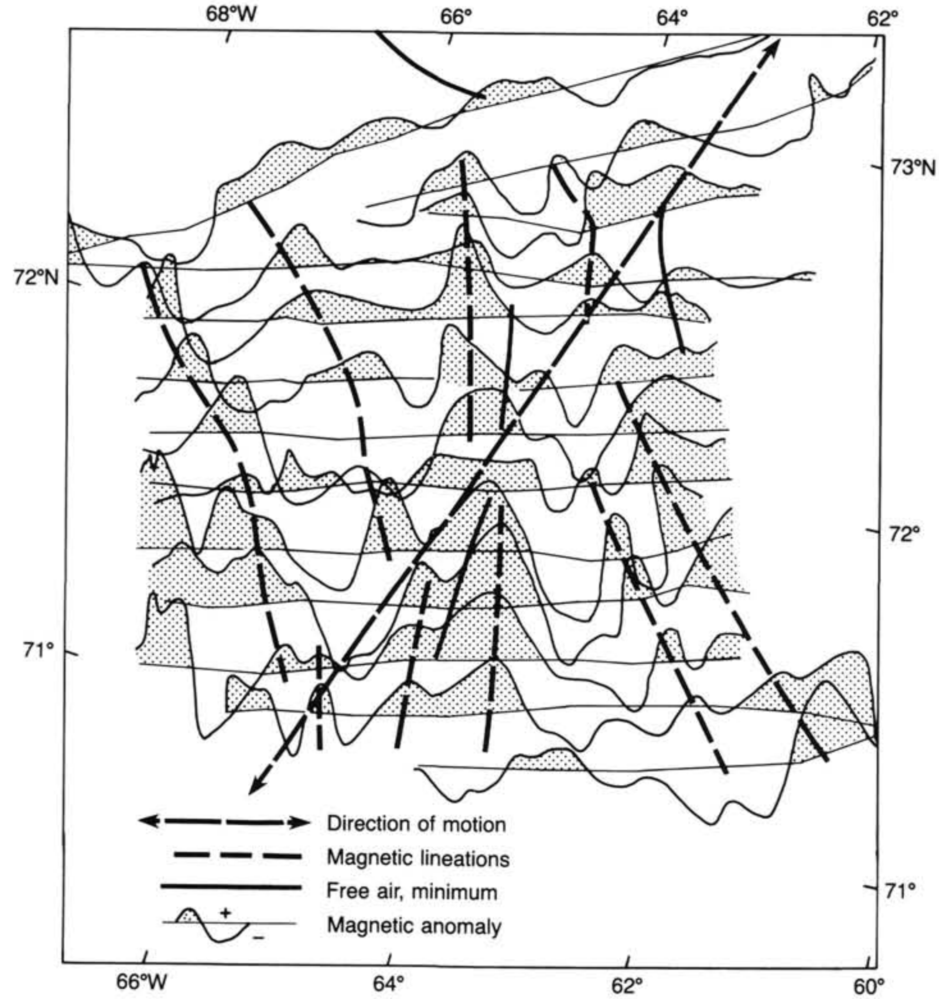

Figure 8. Correlation of magnetic anomalies, direction of plate motion, and trends of gravity lows near ODP Leg 105 drill site BB-3B (Site 645) in Baffin Bay (from Srivastava et al., 1981).

humid conditions that prevailed in the region during the Paleogene.

Perhaps the best indication that warm climates characterized the high latitudes during much of the Paleogene is the floral evidence in Alaska, the Arctic islands, and Ellesmere Island (Wolfe, 1980). Wolfe (1980) reported evidence that the mean annual temperature in the Alaskan region during the middle Eocene was >20°C (megathermal). Early to middle Eocene floras and faunas from the Eureka Sound Formation on Ellesmere characterize mesothermal climates (temperate to warm), the mean annual low temperature having been at least 10°–12°C (Dawson et al., 1976; Henderson et al., 1976). Palms, crocodiles, lemurs, tapir, and small primates are typical floral and faunal elements of this formation. Pederson (1976) and Henderson et al. (1976) documented the occurrence of a rich molluscan-echinoid-coral fauna in the Paleocene Nugssuaq Formation of West Greenland as well as the occurrence of several subtropical to temperate planktonic foraminifers (e.g., *Globocanusa daubjergensis*). The aforementioned evidence coincides with climatic inferences from calcareous planktonic assemblages of the Labrador Sea region (Gradstein and Srivastava, 1980; Fig. 9) and of the northern North Atlantic (Haq et al., 1977), which suggest warm Paleocene climates and sea-surface temperatures and substantial warming during the early and middle Eocene. From oxygen-isotopic analyses of mainly shallow-water calcareous benthic organisms in the North Sea region, Buchardt (1978) provided evidence that warm climates prevailed in the Paleogene north of 50°N. These data also indicate that progressive warming apparently occurred there from late Paleocene through at least middle Eocene time, generally consistent with the other evidence cited. However, the oxygen-isotopic values obtained by Buchardt for the late Paleocene–Eocene interval seem unusually depleted (by perhaps 2 per mil) and give temperature estimates that appear higher than expected for that paleolatitude, even during warm, equable climatic episodes. The isotopically light values could be a result of either diagenetic overprints or perhaps effects of isotopically light runoff to the relatively restricted North Sea region during the Paleogene. Nonetheless, the pattern is similar to isotopic curves produced from other more pelagic regions (e.g., Savin, 1977).

The warm, humid climates that existed during the Paleogene at high northern latitudes are difficult to explain in contrast to the glacial, semiarid climates that currently exist in the region. Speculations about the conditions that caused warm, equable global climates during the Cretaceous–Paleogene consist of explanations related to higher CO_2 partial pressure (Berger, 1977; Berner et al., 1983; Arthur et al., 1985; Barron and Washington, 1985) or to more efficient northward transport of warm oceanic surface waters to the Arctic region through passages, such as the early opening of the Labrador Sea–Baffin Bay corridor (Gradstein and Srivastava, 1980). Other explanations require lower axial tilt and more seasonally balanced solar radiation fluxes to the polar region (Wolfe, 1978, 1980). More compli-

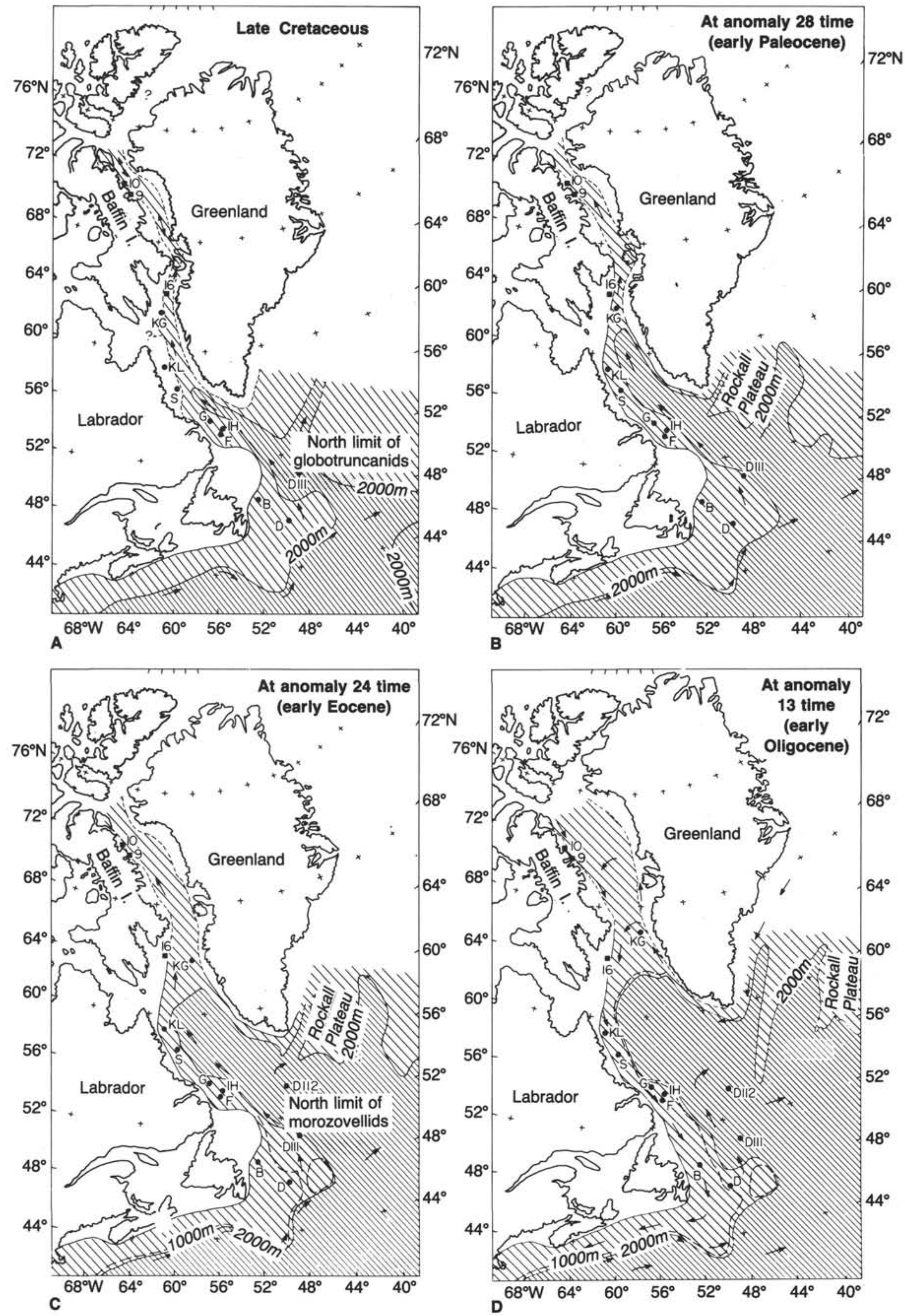

Figure 9. Paleogeography and paleocirculation (surface waters) of Labrador Sea and Baffin Bay for four periods as shown (from Gradstein and Srivastava, 1980). Unshaded areas were emergent during various times.

cated scenarios involving combinations of tectonic and sea-level changes have also been presented (Berger, 1977; Fischer and Arthur, 1977). Warm climatic episodes tend to be associated with highstands of sea level. The warm, equable Paleogene climate of the Labrador Sea–Baffin Bay region is accompanied by a major transgression noted in Labrador Shelf wells (Gradstein and Srivastava, 1980). At present, the relative importance of any one mechanism of climatic change is difficult to demonstrate. However, Barron (1984), using the National Center for Atmospheric Research Community Climate Model and an Eocene paleocontinental reconstruction, demonstrated that the hypothesis of lower axial tilt (Wolfe, 1978) is probably untenable. The simulations produced by the model using a lower axial tilt produced colder, rather than warmer, Eocene paleoclimates in the polar regions. Likewise, using the same atmospheric parameters and paleocontinental positions, climate simulations have demonstrated that the higher sea levels of the Paleogene would have had little overall effect on global climate compared with a lowering of sea level. In other words, the greater albedo associated with relatively larger land area was not significant enough to cause the entire difference between Paleogene and Neogene climates.

One of the major objectives of drilling in Baffin Bay and the Labrador Sea on Leg 105, therefore, is to provide further evidence of the nature of the high-latitude Paleogene climates and to attempt to determine the degree to which warm North Atlantic seawater may have flowed through the early-opened Labrador Sea–Baffin Bay passage (Fig. 9). This passage is probably the only potential path for major exchange of Atlantic surface and deep waters with the Arctic before about middle or late Eocene time because the Norwegian–Greenland Sea did not begin to open until after the early Eocene. We hoped that the nature of this exchange could be ascertained by the planned drilling, study of regional seismic and well data, determination of the history of opening and subsidence of Davis Straits and Baffin Bay, and study of the planktonic and benthic faunas and floras in the region. We recognized, however, that uncertainty would remain even after such studies because the histories of Lancaster Sound and Nares Strait are poorly constrained at present.

Eocene–Oligocene Climatic Deterioration

After the generally warm global climates of most of the Cretaceous, the late Eocene and Oligocene apparently brought cooler and more arid global climatic conditions. Isotopic paleotemperature records from equatorial and high-latitude sites (Savin, 1977) exhibit significant decreases in surface-water temperatures at or near the Eocene–Oligocene boundary (Shackleton and Kennett, 1975). Deep-water temperatures also appear to have decreased in the late Eocene to early Oligocene (Shackleton and Kennett, 1975; Miller et al., 1982). Buchardt's (1978) data from the North Sea region suggest major cooling during the early Oligocene, but, as he points out, the zone assigned to the earliest Oligocene could be placed as the last interval of the Eocene. This indicates a significant problem in paleoclimatology and stratigraphy: relatively few continuous Eocene–Oligocene transitions are known from marine sequences because of widespread hiatuses in formations of that age (Fischer and Arthur, 1977; Moore et al., 1978). The major climatic deterioration and accompanying biotic extinctions appear to have been abrupt and to have occurred near the Eocene/Oligocene boundary (Corliss et al., 1984; Kennett et al., 1985), according to available information from pelagic sequences.

Debate even arises about the significance of the cooling. For example, Matthews and Poore (1980) and Matthews (1984) argued that the synchronous increase observed in oxygen-isotope values of planktonic and benthic foraminifers in the upper Eocene is an ice-volume effect rather than the result of a global temperature change. Although possible, their explanation is not in line with other available data suggesting that major glaciation on Antarctica began about 26 Ma (late Oligocene), as indicated by ice-rafted debris and circum-polar planktonic faunas (Margolis and Kennett, 1971; Hayes and Frakes, 1975; Kennett, 1977). Faunal evidence (Wolfe, 1980) from high northern latitudes indicates a change to cooler and drier conditions in the late Eocene to early Oligocene.

Changes in patterns of deep-water circulation apparently accompanied the cooling near the end of the Eocene. The major increase in production and rate of circulation of bottom water that occurred near the Eocene/Oligocene boundary in the North Atlantic is evidenced by submarine unconformities, the apparent onset of current-influenced sediment drifts, a decrease in the isotopic paleotemperatures as indicated by benthic foraminifers, and a drastic change in the deep-sea benthic foraminiferal faunas (Miller et al., 1982; Berggren and Schnitker, 1983; Miller and Tucholke, 1983). The proposed increased production of deep-water masses may have occurred in the Norwegian–Greenland Sea, although it is not certain that surface-water temperatures were cold enough there or that the Greenland–Scotland Ridge had subsided sufficiently before early middle Miocene time to allow sinking of deep water denser than that produced elsewhere. Perhaps the bottom water was produced in the circum-Antarctic region (Kennett et al., 1985).

Thus, another major objective of the Baffin Bay–Labrador Sea drilling was to recover continuous, high-sedimentation-rate sequences through the Eocene–Oligocene interval to provide better information on the paleoenvironmental and chemical changes (e.g., deep-water oxygenation and carbonate dissolution), biotic evolutionary responses, and sedimentation changes (e.g., sediment source, strength of currents) that accompanied this global turning point. The deep-circulation events could then be dated with more precision, and, together with the knowledge of the climate and paleogeographic/tectonic changes, used to distinguish better the relative roles of deep overflow passages in the Norwegian and Labrador Seas and compare these with one another and with Antarctic sources. Dating the R3/R4 seismic horizon, which lies at the base of the contourite drift deposits in the Labrador Sea and was initially thought to be of either Oligocene or Eocene–Oligocene age (Miller et al., 1982; Miller and Tucholke, 1983), will allow interregional seismic correlations. Our drilling in Baffin Bay was planned to penetrate a reflector of presumed Eocene–Oligocene age, termed the R3 reflector there, which also may represent the effects of the Eocene–Oligocene climatic or circulation event.

Miocene Climate and the Onset of Glaciation in the Northern Hemisphere

Cooling of surface waters apparently occurred in the northern hemisphere high latitudes during the Miocene. At least one warming event is superimposed on that trend. Middle Miocene planktonic biota in the Norwegian Sea are more calcareous and have temperate affinities. A rich, calcareous benthic foraminiferal fauna flourished there (Eldholm, Thiede, Taylor, et al., in press), whereas pollen studies suggest temperate to boreal forests on Iceland, in northwest Europe, and in other high-latitude regions (Wolfe, 1980). By late middle Miocene (about 12.3 Ma), more thick-walled, cold-water radiolarians flourished in Norwegian Sea surface waters (Eldholm, Thiede, Taylor, et al., in press), and floral studies suggest dominance of boreal forests above about 55°N (Wolfe, 1980). Palynological data from clastic deposits in Iceland indicate that significant cooling occurred as early as 9.8 Ma (Mudie and Helgason, 1983), consistent with evidence from western North America (Barnosky, 1983) and Alaska. In fact, Denton and Armstrong (1969) cited evidence of glaciation in Alaska as early as 9–10 Ma.

We are particularly interested in whether cooling occurred earlier in the western North Atlantic region than in the Norwegian Sea–northwest Europe region during the late Cenozoic. It is reasonable to assume that significant climatic gradients existed in an east to west direction (Thiede, 1979) because of the pronounced effect that the Gulf Stream has had on northwest European climate. Drilling in the Labrador Sea and Baffin Bay will provide part of a north-south transect that will connect with sites drilled on Leg 94 (Ruddiman, Kidd, Thomas, et al., 1987) to study both the changing climate and climatic gradients of the late Neogene. In addition, Leg 105 drilling offers an opportunity to examine the exchange of water masses from the Arctic with that of the North Atlantic. Gradstein and Srivastava (1980) suggested that a circulation reversal occurred between Baffin Bay and the North Atlantic some time during the Miocene with formation of the cold Labrador Current flowing out of Baffin Bay during the late Miocene to Pliocene. The planktonic and benthic biota in Baffin Bay sediments compared with that in the Labrador Sea should provide the necessary evidence of such changes in water-mass flow direction.

Perhaps one of the most important results of this investigation will be to date the onset of continental glaciation in the northern hemisphere, at least from circum-Baffin Island. Berggren (1972) suggested a 3.1-Ma date for initiation of ice rafting at DSDP Leg 12 Sites 111 and 116; however, Backman (1979) later assigned an age of 2.5 Ma on the basis of restudy of the same sites. Berggren's date agrees with that of Shackleton and Opdyke (1977), who interpreted the onset of glaciation according to oxygen-isotope curves. Shackleton et al. (1984) subsequently obtained a reliable age of 2.5 Ma for the first appearance of ice-rafted material in cores from the west flank of Rockall Bank in the northeast Atlantic (DSDP Leg 81, Site 552A), a date that was confirmed by results of more recent drilling in the northern North Atlantic (DSDP Leg 94; Ruddiman, Kidd, Thomas, et al., 1987). We therefore expected to see evidence of earlier glaciation in the Baffin Bay region because of its high degree of continentality and because the Arctic record suggests a 5-6 Ma onset of glaciation (Clark, 1982). Furthermore, recent results indicate a possible earlier transition to "polar" environments in the Norwegian-Greenland Sea than south of the Greenland-Scotland Ridge and possible evidence of glaciation as early as 4.3 Ma (Eldholm, Thiede, Taylor, et al., in press).

Glacial Cycles and Rates of Advance and Retreat

Proposed drilling in the Labrador Sea and Baffin Bay was planned to allow a comparison of two different glacial regimes. The Labrador Sea is essentially a part of the North Atlantic province but is also transitional to an Arctic glacial regime typified by the almost fully enclosed Baffin Bay. During glacial times, Baffin Bay was flanked by three major ice sheets: the Innuitian, the Greenland, and the Laurentide. We expected the patterns of warming, cooling, and glacial ice rafting previously outlined for the northern North Atlantic (Ruddiman and MacIntyre, 1981a, 1981b; Shackleton et al., 1984; Ruddiman, Kidd, Thomas, et al., 1987) to hold fairly well for the proposed Labrador Sea sites. The sites in the Labrador Sea are mostly influenced by the Gulf Stream and/or return flow from the Norwegian-Greenland Sea and, therefore, should record events that influenced these oceanographic features. Sites 646 and 647 were not expected to record a major signal of events that occurred at higher latitudes in Baffin Bay, except that Site 647 could possibly have been on the margin of a southward-flowing current from the Baffin Bay region (Figs. 1 and 9).

Different sources of proxy climatic data have led to conflicting models explaining the timing, driving mechanism, and magnitude of glacial-interglacial climatic oscillations (Fig. 10). The prevailing open-ocean model, here referred to as the "North Atlantic Model," is based on a snythesis of oxygen-isotopic data from planktonic and benthic foraminifers and other floral and

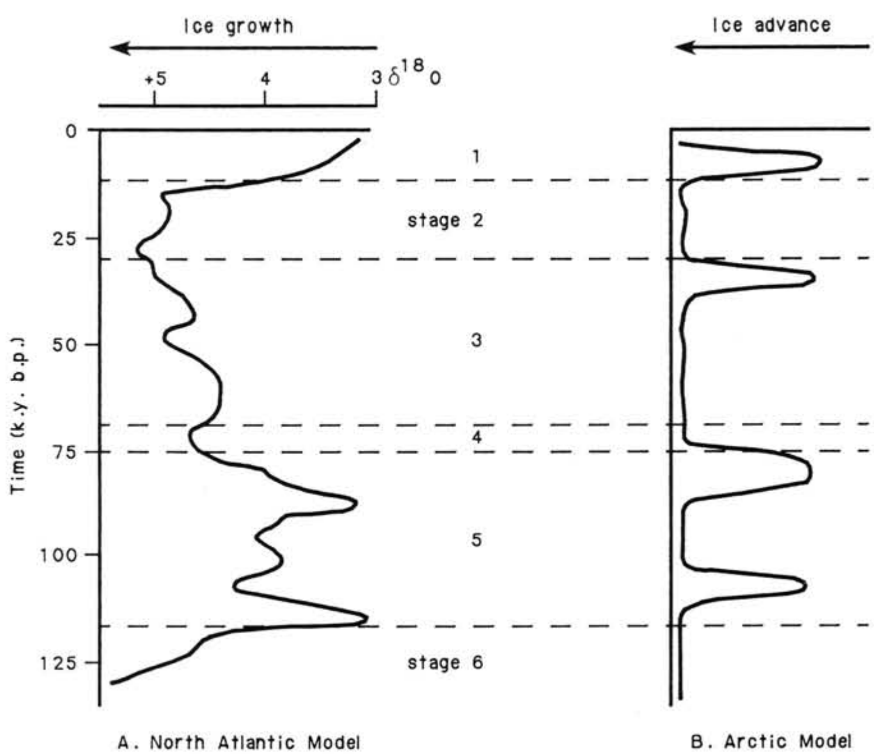

Figure 10. Two "opposing" models for ice-sheet growth based on different types of proxy climatic data from (A) North Atlantic and global studies and (B) regional studies around Baffin Bay.

faunal indicators of sea-surface temperature and salinity (Ruddiman and MacIntyre, 1981a, 1981b). The character of the oxygen-isotope curves suggests long-term buildup of polar and continental ice sheets for as long as about 100 k.y., an initial rapid phase preceded a longer gradual phase and a southward advance of the polar front and then a final rapid deglaciation (in less than 10 k.y.). The rapid disintegration of the marine-based ice sheets was apparently caused by initial warming and melting of ice followed by a rise in sea level, which induced rapid calving and deflation of the ice sheets (Denton and Hughes, 1983). Warming and melting cycles of lower amplitude are thought to be induced by increased solar insolation related to a 23-k.y. precessional cycle (Ruddiman and MacIntyre, 1981a, 1981b).

Another model, called the Arctic Model, was made largely on the basis of dated organic material from raised marine deposits from Greenland and the Canadian Arctic Islands (Andrews et al., 1983; Fig. 10). Ages of marine terraces and morainal material suggest rapid buildup of ice sheets (in less than 15 k.y.) near the ends of interglacial/interstadial intervals characterized by northward penetration of relatively warm Atlantic (subarctic) water masses into Baffin Bay. The model calls for equally rapid glacial terminations. The marine record from above 65°N recovered in piston cores from Baffin Bay (Aksu, 1983) partly supports the Arctic Model, but the oxygen-isotope data combined with the dinoflagellate stratigraphy (Mudie and Aksu, 1984) also appears to confirm a global signal (Figs. 11 and 12).

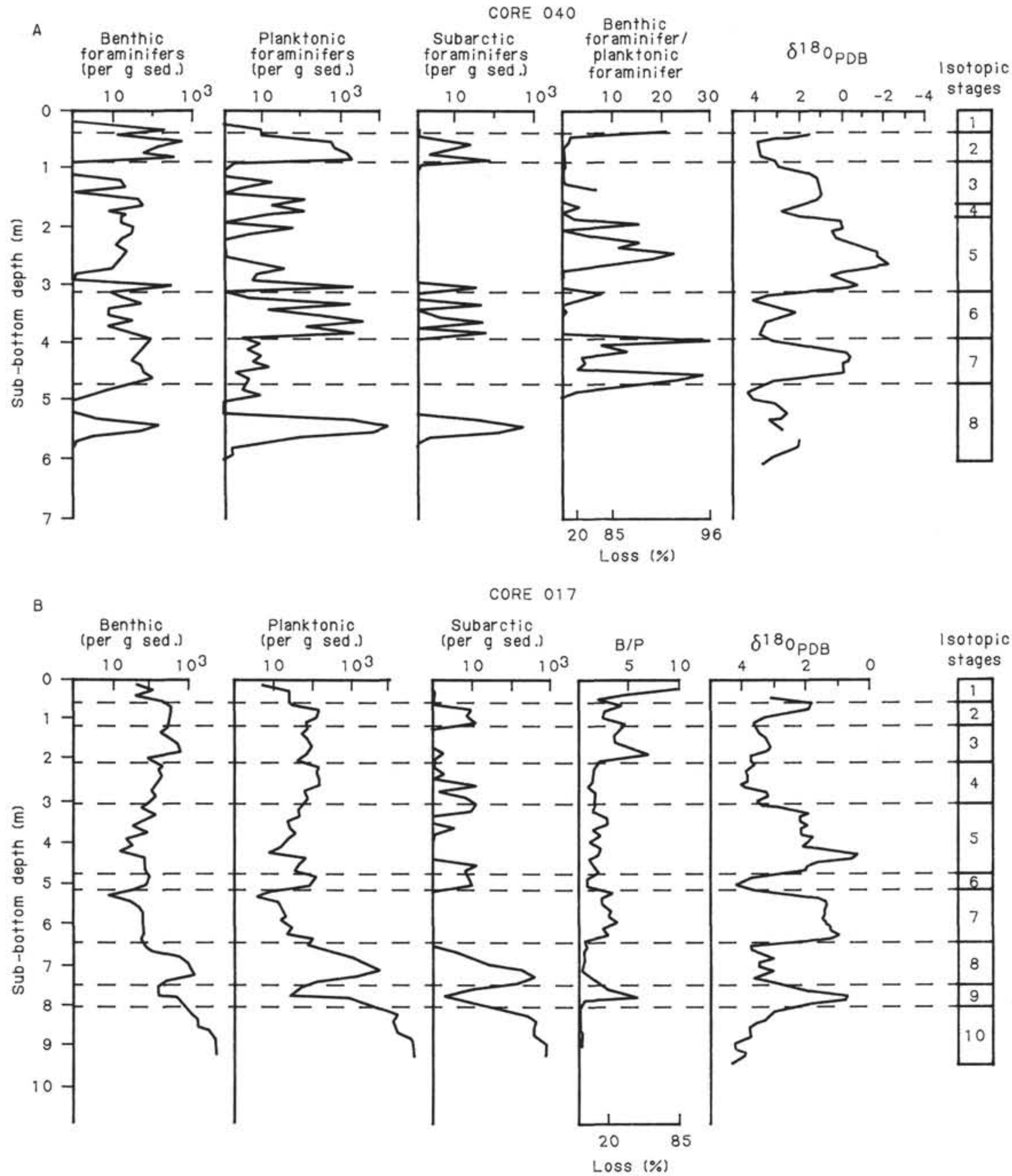

Figure 11. Data from Aksu (1983) for two piston cores in Baffin Bay (A) and Davis Straits (B). Note amplitude of $\delta^{18}O$ values and correlation of oxygen-isotopic stages. Amplitude of Baffin Bay signal is higher (i.e., interglacials are lighter) than that from Davis Strait, which records more normal $\delta^{18}O$ amplitude for glacial-interglacial changes.

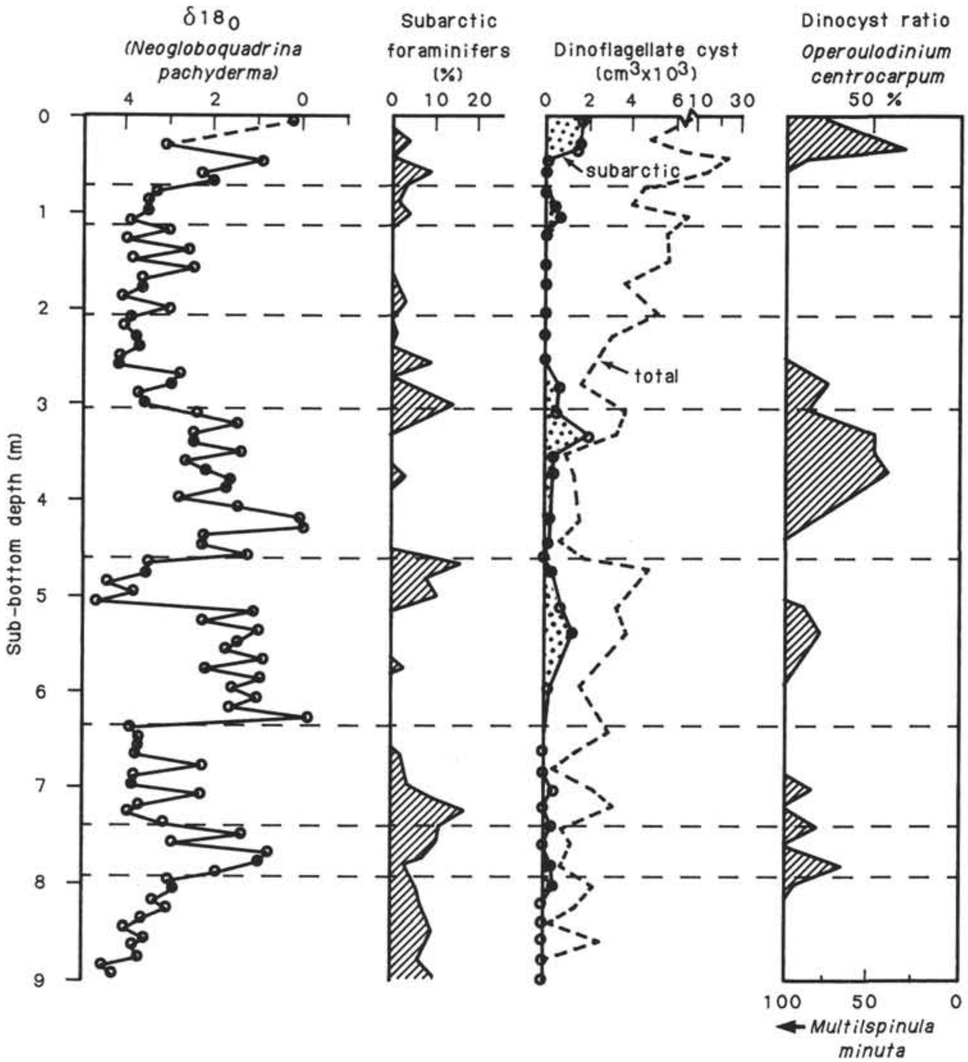

Figure 12. Data from Mudie and Aksu (1984) for a Baffin Bay piston core, showing preferred stratigraphy and indicators of glacial versus interglacial climates.

However, the amplitude of the oxygen-isotope excursions is much greater than the "global" signal by at least 2–3 per mil (Fig. 11), suggesting that glacial meltwaters kept surface salinities low for most of each isotopic stage. Abrupt transitions occurred into what are identified as "glacial" stages. Mudie and Aksu (1984) also found that incursions of subarctic dinoflagellates did not precisely match the occurrences of subarctic foraminifers in the Baffin Bay cores (Fig. 12). This suggests that dissolution may have affected the foraminiferal faunas.

Drilling in both the Labrador Sea and Baffin Bay enabled the recovery of high-sedimentation-rate sequences that allow high-resolution studies of glacial-interglacial paleoenvironment and sedimentation, which will test the aforementioned models. We hoped to examine the relative effects of variations in solar insolation (Hays et al., 1976). Orbital-forcing models indicate that the 41-k.y. obliquity cycle theoretically should dominate at latitudes above 65°N, and the 23-k.y. precessional cycle at lower latitudes. Baffin Bay and Labrador Sea records form an important link between the Arctic record (Mudie, 1982; Aksu, 1984) and the North Atlantic records previously discussed.

REFERENCES

Aksu, A. E., 1983. Holocene and Pleistocene dissolution cycles in deep-sea cores of Baffin Bay and Davis Strait: palaeoceanographic implications. *Mar. Geol.*, 53:331–348.

———, 1984. Climatic and oceanographic changes over the past 400,000 years: evidence from deep-sea cores of Baffin Bay and Davis Strait. *In* Andrews, J. T., and Andrews, N. (Eds.), *Quaternary History of Baffin Island, Baffin Bay and West Greenland*: London (Allen and Unwin), 181–209.

Andrews, J. T., Shilts, W. W., and Miller, G. H., 1983. Multiple deglaciations of the Hudson Bay Lowlands, Canada, since deposition of the Missinaibi (last-interglacial?) formation. *Quat. Res.*, 19:18–37.

Arthur, M. A., Dean, W. E., and Schlanger, S. O., 1985. Cretaceous climate, volcanism and CO_2. *In* Sundquist, E. T., and Broecker, W. S. (Eds.), *Natural Variations in the Carbon Cycle: Archean to Recent*: Washington (Am. Geophys. Union), Geophysical Monograph 32.

Backman, J., 1979. Pliocene biostratigraphy of DSDP Sites 111 and 116 from the North Atlantic Ocean and the age of Northern Hemisphere glaciation. *Stockholm Contribution in Geology* XXXII, 3:115–137.

Barnosky, C. W., 1983. Late Miocene vegetational and climatic variations inferred from a pollen record in northwest Wyoming. *Science*, 223:49–51.

Barron, E. J., 1984. Climatic implications of the variable obliquity explanation of Cretaceous-Paleogene high-latitude floras. *Geology*, 12: 595–598.

Barron, E. J., and Washington, W. M., 1985. Warm Cretaceous climates: high atmospheric CO_2 as a plausible mechanism. *In* Sunquist, E. T., and Broecher, W. S. (Eds.), *The Carbon Cycle and CO_2: Natural Variations Archean to Present*: Washington (Am. Geophys. Union), Geophysical Monograph 32, 546–559.

Berger, W. H., 1977. Carbon dioxide, excursions and the deep sea record, aspects of the problem. *In* Anderson, N. R., and Malahoff, A. (Eds.), *The Fate of Fossil Fuel CO_2 in the ocean*: New York (Plenum Press), 505–542.

Berggren, W. A., 1972. Late Pliocene-Pleistocene glaciation. *In* Laughton, A. S., Berggren, W. A., et al., *Init. Repts. DSDP*, 12: Washington (U.S. Govt. Printing Office), 953–963.

Berggren, W. A., and Schnitker, D., 1983. Cenozoic marine environments in the North Atlantic and Norwegian-Greenland Sea *In* Bott, M.H.P., Saxov, S., Talwani, M., and Thiede, J. (Eds.), *Structure and Development of the Greenland-Scotland Ridge*: New York (Plenum Press), 495–548.

Berner, R., Lasaga, A., and Garrels, R., 1983. The carbonate-silicate geochemical cycle and its effect on atmospheric carbon dioxide over the past 100 million years, *Am. J. Sci.*, 283:641–683.

Buchardt, B., 1978. Oxygen isotope palaeotemperatures from the Tertiary period in the North Sea area. *Nature*, 275:121–123.

Clark, D. B., and Pedersen, A. K., 1976. Tertiary volcanic province of West Greenland. *In* Escher, A., and Watt, W. S. (Eds.), *Geology of Greenland*: Copenhagen (Geol. Surv. Greenl.), 365–385.

Clark, D. B., and Upton, B.G.J., 1971. Tertiary basalts of Baffin Island: field relations and tectonic settings. *Can. J. Earth Sci.*, 8:248–258.

Clark, D. L., 1982. Origin, nature and world climate effect of Arctic Ocean ice-cover. *Nature*, 300:321–325.

Corliss, B. H., et al., 1984. The Eocene-Oligocene boundary event. *Science*, 226:806–810.

Dawson, M. R., West, R. M., Langston, W., Jr., and Hutchison, J. H., 1976. Paleogene terrestrial vertebrates: northernmost occurrence, Ellesmere Island, Canada. *Science*, 192:781–782.

Denton, G. H., and Armstrong, R. L., 1969. Miocene-Pliocene glaciations in southern Alaska. *Am. J. Sci.*, 267:1121–1142.

Denton, G. H., and Hughes, T. J., 1983. Milankovitch theory of Ice Ages: hypothesis of ice-sheet linkage between regional insulation and global climate. *Quat. Res.*, 20:125–144.

Eldholm, O., Thiede, J., Taylor, E., et al., in press. *Proc., Init. Repts.* (Pt. A), ODP, 104.

Fischer, A. G., and Arthur, M. A., 1977. Secular variations in the pelagic realm. *Soc. Econ. Pal. and Mineral.*, Spec. Publ., 25:19–50.

Gradstein, F. M., and Srivastava, S. P., 1980. Aspects of Cenozoic stratigraphy and a paleoceanography of the Labrador Sea and Baffin Bay. *Palaeogeogr., Palaeoclimatol., Palaeoecol.*, 30:261–295.

Grant, A. C., 1982. Problems with plate tectonic models for Baffin Bay-Nares Strait: evidence from the Labrador Sea. *Geoscience*, 8: 313–326.

Haq, B. U., Premoli Silva, I., and Lohmann, G. P., 1977. Calcareous planktonic paleobiogeographic evidence for major climatic fluctuations in the early Cenozoic Atlantic Ocean. *J. Geophys. Res.*, 82: 3861–3876.

Hayes, D. E., and Frakes, L. A., 1975. General synthesis, Deep Sea Drilling Project Leg 28. *In* Hayes, D. E., Frakes, L. A., et al., Init. Repts. DSDP, 28: Washington (U.S. Govt. Printing Office), 919–958.

Hays, J. D., Imbrie, J., and Shackleton, N. J., 1976. Variations in the Earth's orbit: pacemaker of the Ice Ages. *Science*, 194:1121–1132.

Henderson, G., Rosenkrantz, A., and Schiener, E. J., 1976. Cretaceous-Tertiary sedimentary rocks of West Greenland. *In* Escher, A., and Watt, W. S. (Eds.), *Geology of Greenland*: Copenhagen (Geol. Surv. Greenl.), 341–362.

Hinz, K., Schluter, H. U., Grant, A. C., Srivastava, S. P., Umpleby, D., and Woodside, J., 1979. Geophysical transects of the Labrador Sea: Labrador to Southwest Greenland. *In* Keen, C. E. (Ed.), *Crustal Properties Across Passive Margins.* Tectonophysics, 59:151–183.

Hiscott, R. N., 1984. Clay mineralogy and clay-mineral provenance of Cretaceous and Paleogene strata, Labrador and Baffin shelves. *Bull. Can. Pet. Geol.*, 32:272–280.

Jackson, H. R., Keen, C. E., and Barrett, D. L., 1977. Geophysical studies on the eastern continental margin of Baffin Bay and in Lancaster Sound. *Can. J. Earth Sci.*, 14:1991–2001.

Jackson, H. R., Keen, C. E., Falconer, R.K.H., and Appleton, K. P., 1979. New geophysical evidence for sea-floor spreading in central Baffin Bay. *Can. J. Earth Sci.*, 16:2122–2135.

Keen, C. E., 1979. Thermal history and subsidence of rifted continental margins—evidence from wells on the Nova Scotian and Labrador shelves. *Can. J. Earth Sci.*, 16:505–522.

Keen, C. E., and Barrett, D. L., 1972. Seismic refraction studies in Baffin Bay: an example of a developing ocean basin. *Geophys. J. R. Astron. Soc.*, 30:253–271.

Keen, C. E., and Pierce, J. W., 1982. The geophysical implications of minimal Tertiary motion along Nares Strait. *Geoscience*, 8:327–337.

Kemp, E. M., 1978. Tertiary climatic evolution and vegetation history in the southeast Indian Ocean region. *Palaeoclim., Palaeogeogr., Palaeoecol.*, 24:169–208.

Kennett, J. P., 1977. Cenozoic evolution of Antarctic glaciation, the circum-Antarctic Ocean, and their impact on global paleoceanography. *J. Geophys. Res.*, 82:3843–3890.

Kennett, J. P., von der Borch, C., Baker, P., Barton, C., Boersma, A., Cauler, J., Dudley, W., Gardner, J., Jenkins, D., Lohman, W., Martini, E., Merrill, R., Morris, R., Nelson, C., Robert, C., Srinivasan, M., Stein, R., Takenchi, A., and Murphy, M., 1985. Paleotectonic implications of increased late Eocene-early Oligocene volcanism from South Pacific DSDP sites. *Nature*, 316:507–511.

Kerr, J. W., 1967. A submerged continental remnant beneath the Labrador Sea. *Earth Planet. Sci. Lett.*, 2:283–289.

Klose, G. W., Malterre, E., McMillan, N. J., and Zinkan, C. G., 1982. Petroleum exploration offshore southern Baffin Island, Northern Labrador Sea, Canada. *In* Embry, A. F., and Balkwill, H. R. (Eds.), *Arctic Geology and Geophysics*: Calgary (Can. Soc. Pet. Geol.), Mem. 8:245–265.

Kristoffersen, Y., and Talwani, M., 1977. Extinct triple junction south of Greenland and the Tertiary motion of Greenland relative to North America. *Geol. Soc. Am. Bull.*, 88:1037–1049.

Laughton, A. S., Berggren, W. A., et al., 1972. Site 112. *In* Laughton, A. S., Berggren, W. A., et al., *Init. Repts. DSDP*, 12: Washington (U.S. Govt. Printing Office), 161–254.

Margolis, S. V., and Kennett, J. P., 1971. Cenozoic paleoglacial history of Antarctica recorded in subantarctic deep-sea cores. *Am. J. Sci.*, 271:36–48.

Matthews, R. K., 1984. Oxygen isotope record of ice-volume history: 100 million years of glacio-eustatic sea-level fluctuation. *In* Schlee, J. S. (Ed.), *Interregional Unconformities and Hydrocarbon Accumulation*: Tulsa (Am. Assoc. Pet. Geol.), Mem. 36:97–107.

Matthew, R. K., and Poore, R. Z., 1980. Tertiary $\delta^{18}O$ record and glacio-eustatic sea-level fluctuations. *Geology*, 8:501–504.

McWhae, J.R.H., 1981. Structure and spreading history of the northwestern Atlantic region from the Scotian shelf to Baffin Bay. *In* Kerr, J. W., Fergusson, A. J., and Machan, L. C. (Eds.), *Geology of North Atlantic Borderlands*: Calgary (Can. Soc. Pet. Geol.), Mem. 7:299–332.

Miall, A. D., Balkwill, H. R., and Hopkins, W. R., Jr. 1980. *Cretaceous and Tertiary Sediments of Eclipse Trough, Bylot Island Area, Arctic Canada, and Their Regional Setting*. Copenhagen (Geol. Surv. Can. Pap.), 79–123.

Miller, K. G., Gradstein, F. M., Berggren, W. A., 1982. Late Cretaceous to early Tertiary agglutinated benthic foraminifera in the Labrador Sea. *Micropaleontology*, 28:1–30.

Miller, K. G., and Tucholke, B. E., 1983. Development of Cenozoic abyssal circulation south of the Greenland-Scotland ridge. *In* Bott, M.H.P., Saxov, S., Talwani, M., and Thiede, J. (Eds.), *Structure and Development of the Greenland-Scotland Ridge*: New York (Plenum Press), 549–589.

Moore, T. C., van Andel, T. J., Sancetta, C., and Pisias, N., 1978. Cenozoic hiatuses in pelagic sediments. *Micropaleontology*, 24:113–138.

Mudie, P. J., 1982. Pollen distribution in recent marine sediments, eastern Canada. *Can. J. Earth Sci.*, 19:729–747.

Mudie, P. J., and Aksu, A. E., 1984. Palaeoclimate of Baffin Bay from 300,000-year record of foraminifera, dinoflagellates and pollen. *Nature*, 312:630–634.

Mudie, P. J., and Helgason, J., 1983. Palynological evidence for Miocene climatic cooling in eastern Iceland about 9.8 m.y. ago. *Nature*, 303:689–692.

Nilsen, T. H., 1983. Influence of the Greenland-Scotland ridge on the geological history of the North Atlantic and Norwegian-Greenland sea areas. *In* Bott, M.H.P., Saxov, S., Talwani, M., and Thiede, J. (Eds.), *Structure and Development of the Greenland-Scotland Ridge*: New York (Plenum Press), 457–478.

Pederson, K. R., 1976. Fossil floras of Greenland. *In* Escher, A., and Watt, W. S. (Eds.), *Geology of Greenland*: Copenhagen (Geol. Surv. Greenl.), 519–535.

Rice, P. D., and Shade, B. D., 1982. Reflection seismic interpretation and seafloor spreading history of Baffin Bay. *In* Embry, A. F., and Balkwill, H. R. (Eds.), *Arctic Geology and Geophysics*: Calgary (Can. Soc. Pet. Geol.), Mem. 8:245–265.

Rolle, F., 1985. Late Cretaceous–Tertiary sediments offshore central West Greenland: lithostratigraphy, sedimentary evolution, and petroleum potential. *Can. J. Earth Sci.*, 22:1001–1019.

Ruddiman, W. F., Kidd, R., Thomas, E., et al., 1987. *Init. Repts. DSDP*, 94: Washington (U.S. Govt. Printing Office).

Ruddiman, W. F., and McIntyre, A., 1981a. Oceanic mechanisms for amplification of the 23,000-year ice-volume cycle. *Science*, 212:617–627.

________, 1981b. The North Atlantic Ocean during the last deglaciation. *Palaeogeog., Palaeoclim., Palaeoecol.*, 35:145–214.

Savin. S. M., 1977. The history of the earth's surface temperature during the last 100 million years. *Am. Rev. Earth Planet. Sci.*, 5:319–355.

Shackleton, N. J., Backman, J., Zimmerman, H., Kent, D. V., Hall, M. A., Roberts, D. G., Schnitker, D., Baldauf, J. G., Desprairies, A., Homrighausen, R., Huddlestun, P., Keene, J. B., Kaltenback, A. J., Krumsiek, K.A.O., Morton, A. C., Murray, J. W., and Westberg-Smith, J., 1984. Oxygen isotope calibration of the onset of ice-rafting and history of glaciation in the North Atlantic region. *Nature*, 307:620–623.

Shackleton, N. J., and Kennett, J. P., 1975. Paleotemperature history of the Cenozoic and the initiation of Antarctic glaciation: oxygen and carbon isotope analyses in DSDP Sites 277, 279, and 281. *In* Kennett, J. P., Houtz, R. E., et al., *Init. Repts. DSDP*, 29: Washington (U.S. Govt. Printing Office), 743–755.

Shackleton, N. J., Opdyke, N. D., 1977. Oxygen isotope and palaeomagnetic evidence for early Northern Hemisphere glaciation. *Nature*, 270:216–219.

Srivastava, S. P., 1978. Evolution of the Labrador Sea and its bearing on the early evolution of the North Atlantic. *Geophy. J. R. Astron. Soc.*, 52:313–357.

________, 1983. Davis Strait: structures, origin, and evolution. *In* Bott, M.H.P., Saxov, S., Talwani, M., Thiede, J., (Eds.), *Structure and Development of the Greenland-Scotland Ridge; New Methods and Concepts*: NATO Conference Series IV (8):159–189.

Srivastava, S. P., Falconer, R.K.H., and MacLean, B., 1981. Labrador Sea, Davis Strait, Baffin Bay: geology and geophysics—a review. *In* Kerr, J. W., Fergusson, A. J., and Machan, L. C. (Eds.), *Geology of the North Atlantic Borderlands*: Calgary (Can. Soc. Pet. Geol.), Mem. 7:333–398.

Srivastava, S. P., MacLean, B., MacNab, R. F., and Jackson, H. R., 1982. Davis Strait: structure and evolution as obtained from a systematic geophysical survey. *In* Embry, A. F., and Balkwill, H. R. (Eds.), *Arctic Geology and Geophysics*: Calgary (Can. Soc. Pet. Geol.), Mem. 8:267–278.

Srivastava, S. P., and Tapscott, C. R., 1986. Plate kinematics of the North Atlantic. *In* Vogt, P. R. and Tucholke, B. E., (Eds.), *The Geology of North America: the Western Atlantic Region*: Boulder (Geological Society of America), DNAG Series, Vol. M, 379–404.

Theide, J., 1979. History of the North Atlantic Ocean: evolution of an asymmetric zonal paleo-environment in a latitudinal ocean basin. *In* Talwani, M., Hay, W., and Ryan, W.B.F. (Eds.), *Deep Drilling Results in the Atlantic Ocean: Continental Margins and Paleoenvironment*: Washington (American Geophysical Union), Maurice Ewing Series 3:275–296.

Thiede, J., and Eldholm, O., 1983. Speculations about the paleodepth of the Greenland-Scotland ridge during late Mesozoic and Cenozoic times. *In* Bott, M.H.P., Saxov, S., Talwani, M., and Thiede, J. (Eds.), *Structure and Development of the Greenland-Scotland Ridge*: New York (Plenum Press), 445–455.

Van Houten, F. B., 1982. The geologic record of weathering and soils. *In* Berger, W. H., and Crowell, J. C., (Eds.), *Climate in Earth History*: Washington (Natl. Res. Council, Geophysics Study Comm., NAS), 81–90.

Wolfe, J. A., 1978. A paleobotanical interpretation of Tertiary climates in the Northern Hemisphere. *Am. Sci.*, 66:694–703.

________, 1980. Tertiary climates and floristic relationships at high latitudes in the Northern Hemisphere. *Palaeogeogr., Palaeoclimat., Palaeoecol.*, 30:313–323.